

**BEFORE THE PUBLIC UTILITIES COMMISSION OF THE
STATE OF CALIFORNIA**



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Order Instituting Rulemaking to Implement Dairy
Biomethane Pilot Projects to Demonstrate
Interconnection to the Common Carrier Pipeline
System In Compliance with Senate Bill 1383

Rulemaking 17-06-015
(Filed June 22, 2017)

**JOINT COMMENTS OF COMMUNITY ALLIANCE FOR AGROECOLOGY AND
CENTER ON RACE, POVERTY AND THE ENVIRONMENT**

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August 3, 2017

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INTRODUCTION

On behalf of the Community Alliance for Agroecology (“CAFA”) and the Center on Race Poverty and the Environment (“CRPE”), we respectfully submit these Joint Comments regarding this rulemaking. Our comments correspond to the issues identified in the Order Instituting Rulemaking (hereafter “Order”), with additional comments on the CEQA Guidance.

1. Should the CPUC adopt the definition of Pipeline Infrastructure?

Currently, the Order proposes defining “Pipeline Infrastructure” as including biogas collection lines, the point of receipt, and the pipeline extension. Order, Appendix A at 6. The proposed definition of Pipeline Infrastructure should be revised to exclude biogas collection lines. Accordingly, we agree with the position of Bioenergy Association of California, Quantitative Biosciences, RNG Coalition, and PG&E on this issue.

Because the Order states that dairy biomethane producers are eligible for revenue from the sale of biomethane, as well as credits from the Low Carbon Fuel Standard, the Renewable Fuel Standard, cap and trade offset revenue, projects should be fully responsible for the cost of

production and generation of biomethane, including biogas collection lines to transport biogas to the conditioning facility for conversion to biomethane. Additional subsidies for dairy biomethane projects may also be available, including appropriations from the Greenhouse Gas Reduction Fund.¹ The definition of pipeline infrastructure should thus not include biogas collection lines so that ratepayers are not required to subsidize production of biomethane and utilities are not required to own a portion of a natural gas production facility. *See* Order, Appendix A at 7 (citing Natural Gas Wellhead Decontrol Act and Natural Gas Policy Act).

The Order incorrectly infers that biogas collection lines are included in the term pipeline infrastructure within the meaning of Senate Bill 1383. “The biogas collection lines and pipeline extension are used for transporting gas to the utility transmission system and constitute the ‘pipeline infrastructure’ as stated in SB 1383.” Order, Appendix A at 6. Senate Bill 1383 does not define the term “pipeline infrastructure.” Stats. 2016, ch. 395, § 4, p. 93 (codified as Health & Safety Code § 39730.7). Instead, Senate Bill 1383 plainly requires the Commission to provide the pipeline infrastructure, not the infrastructure to produce and deliver biogas to a conditioning facility prior to pipeline injection. Had the legislature wanted to require ratepayers to subsidize the production of biomethane, it would have so stated. Accordingly, given the already abundant subsidies available to dairy biomethane production, the Commission should protect the interests of ratepayers and define Pipeline Infrastructure to exclude biogas collection lines and thus minimize the cost to ratepayers.

Finally, to the extent that a project necessitates that any existing pipeline infrastructure undergo upgrades, repairs, or servicing, then the biomethane producer should be responsible for such infrastructure construction and maintenance costs. Ratepayers should not be responsible for

¹ Dairy Digester Research and Development Fund, available at <https://www.cdfa.ca.gov/oefi/ddrdp/>.

such infrastructure under Senate Bill 1383, which only allows “cost-recovery for the reasonable cost of pipeline infrastructure developed pursuant to the pilot projects” in order “to demonstrate interconnection to the common carrier pipeline system.” Stats. 2016, ch. 395, § 4, subd. (d)(2), p. 93 (codified as Health & Safety Code § 39730.7(d)(2)). The Legislature did not authorize cost-recovery of infrastructure for purposes other than for infrastructure developed for demonstrating interconnection.

2. Should the CPUC adopt the implementation plan?

No comments.

3. Should the CPUC adopt the cost recovery framework?

The Commission should revise the cost recovery framework to allow cost recovery for the point of receipt and the pipeline extension in utilities’ transportation and distribution rates. All costs associated for generation of biogas and conversion to marketable biomethane should be borne by the dairy biomethane producers. Consistent with our comments on Issue #1, utilities should not bear the cost of gathering lines. This is especially appropriate given that dairy biomethane producers may access various forms of subsidies, including sale of Low Carbon Fuel Standard and Renewable Portfolio Standard credits, the sale of cap and trade offsets, and may obtain grant funding from the California Department of Food & Agriculture. Order, Appendix A at 10, footnote 5.

Moreover, the Commission should revise the implementation plan to refund 100% of any project cost savings to ratepayers. The Commission proposes that the costs related to pipeline infrastructure will be recorded in a memorandum account. The Commission will accept the forecasted costs as the bids and those will be authorized as the per se reasonable costs for each pilot. Any cost above that amount would be subject to review. Any savings (below authorized

amount) will be credited 50/50 to ratepayers and utilities shareholders. Because ratepayers must fund the entire amount of this program, and utility shareholders do not, ratepayers should receive the entire savings rebate.

4. Should the CPUC adopt the pilot selection criteria framework?

The Commission should revise the selection criteria framework to account for the lifecycle impacts associated with anaerobic digestion. In order to receive environmental benefits and disadvantaged community credits in the scoring criteria, a project should fully mitigate the impact of GHGs, criteria pollutants, toxic air contaminants, and all forms of nitrogen released as part of the anaerobic digestion process and digestate handling, including application of solid and liquid manure to crop land. Such releases should include, but not limited to, oxides of nitrogen (including the greenhouse gas nitrous oxide), ammonia, methane, and nitrate. It is well established that over-application of nitrogen to crop land results in nitrate contamination of groundwater. Moreover, the handling of digestate after anaerobic digestion releases both methane, nitrous oxide and ammonia.² Ammonia is a precursor to fine particulate matter (PM_{2.5}). Projects that result in the least net GHGs and criteria pollutants should receive the most points, and applicants should document the manner in which digestate would be managed to document predicted emissions.

Furthermore, one of the more problematic criteria is the suggestion that a group of dairy operations may form a centralized digester. This idea suggests the possibility for increased local production of GHGs, toxic air contaminants, and criteria pollutants as a result of anaerobic digestion thus creating cumulative impacts in a given geographic area which may also qualify as

² See Michael A. Holly, et al., Greenhouse gas and ammonia emissions from digested and separated dairy manure during storage and after land application, Agriculture, Ecosystems and Environment 239(2017) 410-419, (“Holly Study”), attached as Exhibit 1.

a disadvantaged community. The process of allowing such operations to receive selection criteria points has the unintended consequence of encouraging a locally cumulative impact.

5. Should the CPUC adopt the data gathering parameters?

The Data Gathering Parameters must ensure that the Commission will gather critical performance data as part of the pilot projects to evaluate emissions reductions/increases from anaerobic digestion and other impacts. The Holly Study documents the need to evaluate the amount of emissions after anaerobic digestion, and evaluate that compared to baseline conditions. For example, the Holly Study found that ammonia increased by 81 percent.³ The Holly Study also found that anaerobic digestion reduced methane from manure management by between 25 and 40 percent, depending on management practices.⁴ Evaluation of methane reduction performance, including post-digestion methane emissions, are critical for assessing the merit of anaerobic digesters as a methane control strategy.

The Data Gathering Parameters require project developers to allow state agencies to undertake reasonable research projects. Order, Appendix B at 3. Such monitoring and research by state agencies is not currently required. The Commission should commit, as part of this proceeding, to partner with the State Air Board and State Water Board to secure necessary funding and to monitor the pilot projects for air and water impacts.

The Order requires developers to allow monitoring of emissions (GHG and criteria) and emissions reductions. Order, Appendix B at 17-18. The CPUC should amend the emissions monitoring provision to specifically require projects to allow monitoring of methane, nitrous

³ Holly, et al. at 417.

⁴ Holly, et al. at 416.

oxide, criteria pollutants, and toxic air contaminants from anaerobic digestion, handling of post-digestion manure, and any other air emissions from a project.

The Data Gathering Parameters does not include manure application monitoring, and should be amended to include evaluation of nutrients (nitrogen, phosphorus, etc.) applied to crop fields, including nitrate migration below the root zone.

6. Does the proposed implementation framework support the safe provision of natural gas services?

The proposed implementation framework does not support the safe provision of natural gas services. The projects should fully mitigate air and water impacts associated with as discussed below.

7. Comments on CEQA Guidance.

The CEQA Guidance lists several requirements to “meet air quality requirements.” Order, Appendix B at 12-14. The Guidance should be amended to reflect several issues. First, ammonia mitigation should be included in the Guidance, especially after the Holly Study reported a significant increase in ammonia emissions as a result of anaerobic digestion. Ammonia is both a toxic gas and reacts to form ammonium nitrate, a fine particle (PM_{2.5}) and criteria pollutant.

Second, Air Quality 1.b requires Best Available Control Technology for on-site electricity generation. *Id.* at 13. Mitigation for on-site electricity generation should mandate criteria pollutant and toxic air contaminant performance standards at least as stringent as that achieved on a per megawatt/hour basis by BACT at the most efficient combined cycle natural gas power plant.

Combusting biogas in internal combustion engines for on-site electricity generation yields significant NO_x, SO_x, VOC, and particulate matter emissions that negatively affect air quality.⁵ The 2015 study “Assessment of the Emissions and Energy Impacts of Biomass and Biogas Use in California” finds that using current technology for biogas electricity generation results in a net increase of criteria pollutants. The current permitting of digesters by the San Joaquin Valley Unified Air Pollution Control District demonstrates and supports this study’s findings when the District only requires internal combustion engines as Best Available Control Technology.⁶ For example, a single dairy digester project – Lakeview Dairy – with two internal combustion engines producing 1,059 kw of electricity emits air pollution for which the facility does not need to purchase offsetting emission reduction credits.⁷ This means that the digester adds pollution to the air basin without offsetting mitigation.

One can reasonably extrapolate the impact from 25 dairies each emitting 5.68 tons per year of NO_x each without obtaining any offsets. Considering the permitted 600 megawatt Avenal Power Center’s maximum NO_x emissions of 99.4 tons/year,⁸ the dairies would generate 4.41 percent of the electricity Avenal generates yet emit more NO_x, SO_x, and VOC.⁹ The Avenal Power Center had to buy offsets pursuant to Air District Rule 2201 and the Lakeview

⁵ Assessment of the Emissions and Energy Impacts of Biomass and Biogas Use in California (2015) (“Biogas Impact Assessment”), available at <https://www.arb.ca.gov/research/rsc/1-30-15/item6dfr11-307.pdf>

⁶ See, e.g., Notice of Preliminary Decision – Authority to Construct, Lakeview Dairy Biogas at 7, available at [http://www.valleyair.org/notices/Docs/2016/03-22-16_\(S-1143770\)/S-1143770.pdf](http://www.valleyair.org/notices/Docs/2016/03-22-16_(S-1143770)/S-1143770.pdf)

⁷ *Id.* at 1, 20.

⁸ Notice of Final Determination of Compliance, Avenal Power Center at 3, 27, attached as Exhibit 2.

⁹ Digester/Avenal Comparison, attached as Exhibit 3.

Dairy did not.¹⁰ This adds air pollution to the air basin, would displace cleaner power with dirty “renewable” dairy biogas, and negatively affect Valley communities. Given the air pollution from on-site electricity generation, such impacts should be fully mitigated.

The CEQA guidance should not allow air quality impacts of the project to be offset by use of renewable fuel produced by the project. Order, Appendix B at 13. The greatest air quality benefit will occur if the project mitigates air pollution on-site so as not to burden disadvantaged communities when emissions reductions occur off-site. In other words, diesel PM2.5 reduced by using biomethane would have impacts where combusted, and not necessarily in the same immediate vicinity as the project. Thus, offsetting emissions will not benefit local communities.

Water quality provisions only address the lining of lagoons. Order, Appendix B at 14. The CEQA guidance should include the requirement to monitor nitrogen application to crop fields to prevent ground water impacts from nitrogen-rich digestate.

Conclusion.

For the reasons stated above, the Commission should amend the Order.

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Respectfully submitted,

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¹⁰ Notice of Final Determination of Compliance, Avenal Power Center at 38.

Exhibit 1



Greenhouse gas and ammonia emissions from digested and separated dairy manure during storage and after land application



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ABSTRACT

Manure management at dairy production facilities, including anaerobic digestion (AD) and solid-liquid separation (SLS), has shown strong potential for the abatement of greenhouse gas (GHG) and ammonia (NH₃) emissions. However, previous study results are inconsistent and the combined effect of AD + SLS remains to be quantified. This study evaluated the effects of AD, SLS, and AD + SLS on GHG and NH₃ emissions during manure storage through land application over nine months. AD and SLS alone significantly ($P < 0.05$) reduced total GHG emissions for storage and land application compared to untreated manure slurries by 25% and 31%, respectively. The majority of that reduction was from methane during storage. SLS had a greater potential for methane reduction in storage than AD, but the variability in digester performance likely impacts the reduction potential. Digestion with subsequent separation further decreased CH₄ emissions from 3.9 g CO₂-eq to 1.3 g CO₂-eq, but increased emissions of nitrous oxide (N₂O) from 0.6 g CO₂-eq to 2.0 g CO₂-eq during storage eliminating a further reduction of GHG emissions as compared to AD alone. AD resulted in a gas emission tradeoff as it increased NH₃ emissions by 81% during storage, which could be mitigated by subsequent SLS, manure storage covers, or other beneficial management practices.

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1. Introduction

In 2013, 7.7% of all U.S. greenhouse gas (GHG) emissions were from agricultural sources. Gaseous losses from ruminant livestock in the form of manure management were responsible for 15.2% of agricultural emissions (USEPA, 2015). In addition, GHG emissions from dairy manure management increased by 53% from 1990 to 2012 and are expected to continue to rise; therefore, it is critical to recommend efficient manure management mitigation strategies to dairy producers to abate overall agricultural GHG emissions (USEPA, 2015). Many different strategies have demonstrated potential to reduce methane (CH₄), nitrous oxide (N₂O), and ammonia (NH₃) emissions from manure (Montes et al., 2013; Ndegwa et al., 2008). For example, manure processing using anaerobic digestion (AD) can reduce CH₄ emissions and solid-liquid separation (SLS) can reduce both CH₄ and N₂O emissions

(Amon et al., 2006; Chadwick et al., 2011; Clemens et al., 2006; Meyer-Aurich et al., 2012).

AD is a microbial process that degrades organic material, such as cattle manure, in the absence of oxygen, producing biogas, which is primarily composed of CH₄ and carbon dioxide (CO₂). Biogas can be captured and combusted to generate electricity, directly burned for heating applications, or further upgraded for use in higher value applications such as vehicle fuel. These processes reduce the net emissions impact from feedstocks natural decomposition as CH₄ in biogas is converted to CO₂ during combustion. When CH₄ is captured and used as an energy source it can also reduce the life cycle depletion of fossil fuels from manure management at a dairy facility by 43% as grid-based electricity is replaced by biogas-based electricity (Aguirre-Villegas et al., 2014). The effluent leaving the digester, known as digestate, has modified chemical content (e.g. total solids, carbon, ammonium (NH₄), and pH), contains more soluble plant nutrients due to mineralization, and has less degradable biomass than the original substrate resulting in changes in GHG and NH₃ emissions (Clemens et al., 2006). These changes can result in an additional benefit as the effluent from the digester has reduced organic matter, which has

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shown potential to mitigate GHG emissions during storage and after land application (Amon et al., 2006; Clemens et al., 2006; Hafner et al., 2013). Amon et al. (2006) found that digestion reduced total GHG emissions by 60% from the untreated slurry due to the reduction of CH₄ emissions, however the results from this study should be used with caution as there was no replication.

While there exists a potential for GHG emissions reductions, a tradeoff may exist in using digestion to mitigate manure GHG emissions, as some of the changes in the manure composition can promote NH₃ emissions following digestion. During the AD process, methanogens and other microorganisms break down proteins, amino acids, and urea forming NH₄ (Bernet et al., 2000). In addition, mineralization of organic N and volatile fatty acids during AD increases manure pH and available N (Petersen and Sommer, 2011), factors which increase NH₃ emissions. Despite these known mechanisms, studies measuring NH₃ emissions after AD have been inconsistent. Amon et al. (2006) found that NH₃ emissions from digested manure storages were similar to untreated. After application, this same study found that NH₃ emissions for the digested manure were 15% greater than the untreated manure. On the contrary, Neerackal et al. (2015) reported significantly higher NH₃ emissions from manure storage after AD, but a reduction of NH₃ emissions after manure land application. In addition, the variability in results highlights the importance of conducting additional research that explores the effect of AD on NH₃ emissions.

Solid-liquid separation is a process in which manure solids are mechanically separated from manure liquids to reduce storage capacity and increase flexibility of manure management (Christensen et al., 2013). The liquid portion after separation has a lower amount of organic matter and carbon available for methanogenesis resulting in lower CH₄ production potential. In comparison with liquid manure, storage of separated manure solids results in an environment that is predominately aerobic, eliminating the anaerobic conditions necessary for CH₄ production and thus decreasing CH₄ emissions. Fanguiero et al. (2008) found that separate storage of the liquid and solid fraction resulted in a reduction of CH₄ emissions of approximately 35% when compared to the raw manure. Further reductions during storage may be possible if AD is utilized before separation as it can lower carbon in the manure prior to separation, but exploring the effect of combining AD and SLS on GHG and NH₃ emissions has been largely absent from the literature.

Similar to AD, a tradeoff may exist in reduction of gaseous emissions from SLS as it can increase NH₃ and N₂O emissions in the separated solids. Aerobic solid manure storage systems promote the production of NH₄ and without a subsequent anaerobic environment for nitrification some NH₄ is volatilized as NH₃ (Hansen et al., 2006). As with AD, the results have been inconsistent regarding the effects of SLS on emissions. Amon et al. (2006) found that SLS increased total NH₃ and N₂O emissions from storage and application by 77% and 19% respectively, with a majority of emissions from the composting of the solid portion. Conversely, Hou et al. (2015) observed no significant difference in N₂O emissions between separated liquids from unprocessed manure and reported that the separated solids show lower N₂O emissions than unprocessed manure in terms of percentage of N applied. Neerackal et al. (2015) also found no significant difference of NH₃ emissions between raw manure and separated liquids.

Altering the composition of manure through AD and SLS can affect GHG and NH₃ emissions from downstream processes, which highlights the importance of keeping track of the emissions throughout all manure handling steps. Studies have focused on specific processing technologies (e.g. only storage or only land application) or specific emissions (Dinuccio et al., 2011; Koirala et al., 2013; Neerackal et al., 2015) but there is limited literature

quantifying both GHG emissions and NH₃ emissions from both manure storage and land application and from the same manure stream. Amon et al. (2006) conducted a more comprehensive assessment of emissions from stored and applied manure, but the study contained no replication and followed emission for only 20 days after application. While the prior work conducted in this area was critical to develop data trends, continued work is needed to provide more comprehensive evaluation of manure processing systems, particularly the combination of processing systems. This study is one of the first to compare the magnitude and direction of GHG and NH₃ emissions from manure storage and land-application after combined AD and SLS from the same manure stream.

Literature on CO₂ emissions from processed manure using AD and SLS is also limited. Researchers generally do not quantify gaseous losses of CO₂ from manure as they have been previously absorbed and metabolized by plants that constitute the dairy ration, thus, being part of the carbon cycle and not an additional source of CO₂ (Kulling et al., 2001). While this logic is sound, it is still important to quantify CO₂ emissions to understand the carbon cycling at a dairy farm. In this study, we investigated the influence of AD, SLS, and the combination of AD and SLS on CO₂, CH₄, N₂O, and NH₃ emissions during storage and for one growing season after manure application to the field.

2. Methods & materials

Emissions from processed and unprocessed manure during storage and land application were monitored for CH₄, CO₂, N₂O, and NH₃. Manure collected was measured over a 182-day storage study and upon completion was applied to the field where gas measurements continued for 126 days.

2.1. Manure collection and storage

Manure streams were collected in the pump room of two dairy facilities in 0.21 m³ barrels for the storage portion of the study. Raw manure at farm 1 (R1), digested manure at farm 1 (D1), digested separated liquids at farm 1 (DL1), and digested separated solids at farm 1 (DS1) were collected from a dairy with a mixed plug-flow digester and screw press separators. The digester operates at a mesophilic range and is loaded with skid steer collecting manure three times per day. Two Bauer™ model # 855 screw press separators are used at the facility for manure solid-liquid separation after digestion with a 260 mm press and 520 mm dewatering section with 0.5 mm screen widths. After separation, at this facility, the digested solids are used for bedding and the separated liquids are stored and then land applied. Raw manure at farm 2 (R2), separated liquid at farm 2 (L2), and separated solids at farm 2 (S2) were collected from the USDA dairy facility located in Prairie du Sac, WI. The dairy uses wheat straw for bedding and collects manure with an automatic scraper. Manure is then pumped to a Vincent™ KP-10 screw press separator with a 372 mm press section and 800 mm dewatering section with 0.381 mm screen widths. Manure was collected from two farms as sampling digestion and separation alone and the combination of the two was not possible at the farm scale. At farm 1 only digested manure (D1) was an input to the separator and no infrastructure existed to separate only R1, therefore an additional farm was required to analyze the effects of separation alone.

Manure slurries and separated liquids were stored in 0.21 m³ plastic barrels filled with 0.185 m³ of each manure stream from November 2013 to May 2014. In Wisconsin, separated solid piles are often stored in large unturned piles, impeding oxygen supply. Therefore, separated solids in the study were stored in barrels with the lid open. A headspace of 15–20 cm was left at the top of the barrel for gas emission measurements. The mass of manure was

measured at the beginning and end of the storage period (Table A.1 found in the Appendix) and the exact headspace was measured weekly to calculate gas fluxes. Manure streams were collected in triplicate and one barrel was left unfilled to measure ambient air gas concentration as a control.

The manure barrels were stored in an open barn which ranged in temperature from 1 to 18 °C during the study period and were open to the environment when emissions measurements were not being collected to simulate actual manure storage conditions (including digestate which is stored in uncovered anaerobic storages). Concentrations of CH₄, CO₂, N₂O, and NH₃ were measured from the headspace of the barrel once a week by placing a lid over each barrel and using the a Gasmet™ Fourier Transform Infrared Spectroscopy (FTIR) gas monitor (Model DX4030, Gasmet Technologie Oy, Helsinki, Finland) that detected gaseous compounds by absorbance of infrared radiation at 10 s intervals (Powell and Vadas, 2016). The lid connecting the FTIR to the barrel was designed with an inlet, outlet, and an 18 mm diameter opening to vent to the atmosphere and equilibrate pressure from within the barrel to the barn. The chamber headspace air was pulled into the FTIR for CH₄, CO₂, N₂O, and NH₃ concentration measurement through the inlet of the chamber, and the air was returned back into the chamber's headspace through the outlet, resulting in closed loop air circulation required for measuring cumulative gas concentrations (Neerackal et al., 2015; Sun et al., 2014a). At the time of sampling, gas was cycled through the FTIR at a rate of 2 L per minute for 7 min and concentrations were measured every 20 s. Immediately before each barrel was sampled, headspace depth and manure temperature were recorded and the FTIR was calibrated with N₂ gas.

A closed loop chamber measurement system was used for its ability to measure low gas concentrations and provide air mass transport required for NH₃ emission measurement. Manure storages with liquid or slurry manure are mainly anaerobic, and without an organic crust at the surface N₂O production is low (Sommer et al., 2000). After manure is applied to the field, most of the CH₄ is released within the first few days from a pool of dissolved CH₄ trapped in the manure (Chadwick and Pain, 1997; Chadwick et al., 2000; Clemens et al., 2006; Sommer et al., 1996). Dynamic chambers with an open air flow system prevent accumulation, reducing concentrations and ultimately decreasing the sampling resolution of CH₄ and N₂O emissions from the study. Additionally, closed loop measurement systems have the advantage over static chambers as their design facilitates air transport as required for NH₃ flux measurement. While static chambers may underestimate NH₃ emissions (Miola et al., 2015), Neerackal et al. (2015) found that closed loop chambers resulted in similar emissions to laboratory evaluations using flux chambers.

Manure samples were collected at the start of the experiment and monthly throughout the storage study. A Sludge Judge® sampler (Nasco, Fort Atkinson, WI, U.S.A.) was used to collect a composite sample along the entire depth of the barrel. Chemical analysis included measurements for pH, electric conductivity (EC), NH₄ + NH₃, total solids (TS), volatile solids (VS), and total kjeldahl nitrogen (TKN), total carbon (total C), acid detergent fiber (ADF), neutral detergent fiber (NDF), and hemi-cellulose (Table A.2). Samples were refrigerated and analyzed for pH and TS analysis within one week, the remaining analysis was completed in 28 days on samples that were diluted and preserved.

Manure characteristics from each manure treatment varied in chemical composition at the beginning of the study. Both D1 and DL1 had greater concentrations of NH₄ + NH₃ compared to R1 (Table 1). Digested manures also had lower solids content, VS, aNDF, hemi-cellulose, and C/N ratio. Separation decreased the solids and carbon content of the liquid portion at both farms from their raw slurries. The separated solids had higher concentrations

Table 1

Initial manure characteristics for all treatments. Farm 1 raw manure (R1), farm 1 digested manure (D1), farm 1 digested separated liquid (DL1), farm 1 digested separated solids (DS1), farm 2 manure (R2), farm 2 separated liquid (L2); farm 2 separated solids (S2).

Characteristics	R1	D1	DL1	DS1	R2	L2	S2
pH	7.9	7.7	7.8	9.2	6.8	6.6	8.9
EC (us/cm)	1236	1468	1620	52	1235	1196	39
NH ₄ + NH ₃ (mg/L)	1219	1488	1524	327	771	804	71
TS%	6.1	5.1	2.9	38.1	2.7	2.1	37.7
VS%	0.84	0.78	0.68	0.91	1.03	0.76	0.90
ADF%	38	38	23	59	20	17	55
NDF%	55	47	23	75	26	23	80
Hemi-Cell%	16.1	8.5	1.5	16.8	6.7	5.4	24.9
Total C%	2.3	1.6	1.1	23.3	1.5	1.2	17.7
TKN%	0.22	0.23	0.24	1.34	0.18	0.18	1.25
C/N	10.4	6.9	4.8	17.3	8.1	6.6	14.2

of all parameters except EC. Subsequent separation following digestion further decreased the VS, ADF, aNDF, and hemicellulose.

2.2. Manure field application

After 182 days of storage, manure was applied in bands to 1.5 m by 2.1 m plots with bare soil and immediately incorporated to a depth of 17 cm at the USDA Dairy Forage Research Station in Prairie du Sac, WI in May 2014. Manure was applied to plots at an application rate of 320 kg N ha⁻¹, Table 1. Application rates were determined using the TKN content of the manure sampled on day 124 of the storage experiment, 58 days before the application of manure. Emissions of N₂O and NH₃ in the days prior to the application were measured and used to estimate N lost from each manure treatment from day 124 to the day of application which was less than 5%. The percentage of ammoniacal-N was different between treatments and the liquid slurries had more available N applied (Table A.1). Typical N application rates in Wisconsin range from 140 to 235 kg available N ha⁻¹ for loamy soils with a high yield potential (Laboski and Peters, 2012). A supplemental application of urea at a rate of 82.6 kg N ha⁻¹ was applied 44 days after manure application to simulate actual field conditions, as a supplemental N application is often necessary for corn as indicated by the recommended N application rates. The urea was pretreated with a nitrogen stabilizer with a urease inhibitor, Agrotain® Ultra, at a rate of 3.1 L per metric ton of urea. A control plot that did not receive any manure was established to capture soil gas fluxes.

Treatments were applied to the field using a randomized complete block design. Each barrel was applied to two plots and therefore the number of replicates from the storage to field study went from three to six. The digested solids, DS1, were not applied to the field as digested solids are commonly used for bedding or other purposes and not land applied. Four rows of field corn were planted in each plot at 76.2 cm apart making up two border rows and four rows for harvest analysis. A rectangular 0.3 m² anchor was placed near the center of each plot and a chamber lid was placed on the anchor once a week to calculate CH₄, CO₂, N₂O, and NH₃ flux using the Gasmet™ FTIR gas analyzer described above. The chamber lid consisted of a 0.03 m³ rectangular lid with three 6.35 mm cylindrical tube ports one for the inlet, one for the outlet, and one exposed to the atmosphere for pressure equilibration. Emissions of CH₄, CO₂, N₂O, and NH₃ from field plots were measured following a similar protocol to that of field manure storage studies. Soil temperature and moisture were measured during each gas flux measurement. Soil samples were taken every other week during the trial at a 0–10 cm and 10–20 cm depth for analysis of NO₂ + NO₃ and NH₄ + NH₃.

2.3. Data analysis

Cumulative emissions, expressed in terms of carbon dioxide equivalents ($\text{CO}_2\text{-eq}$), were calculated using piecewise interpolation between sampling points and were determined for a 100 year horizon with characterization factors of 25 for CH_4 and 298 for N_2O (CML, 2001). Biotic CO_2 emissions from manure were not incorporated in the total GHG emission accounting, but are included in the study for carbon balance purposes. Indirect N_2O emissions from NH_3 volatilization were not included in the analysis.

To compare processed solid and liquid manures after AD and SLS, emissions were calculated per mass of raw unprocessed manure for each scenario. The separation efficiency was calculated based on TS for all separated manures to conduct an equivalent comparison between scenarios. Based on these efficiencies, 97% of the raw manure from farm 1 goes to the liquid fraction (DL1) and 3% goes to the solid fraction (to DS1), and 99% of the raw manure from farm 2 goes to the liquid fraction (L2) and 1% to the solid fraction (S2). Finally, gas emissions from the separated solids and liquids were multiplied by mass fraction corresponding to the raw manure and totaled for comparison. Combined liquids and solids at farm 1 are designated DL1+DS1 and L2+S2 at farm 2.

A one tailed *t*-test assuming equal variance was conducted to compare initial characteristics of raw manure and processed manure at the same farm. Statistical analysis was performed using the SAS software version 9.4 (SAS Institute Inc., Cary, North Carolina). A one-way ANOVA (Proc ANOVA) was calculated to determine statistical differences between manure characteristics and gaseous emissions separately for manures from farm 1 and farm 2. A Tukey's studentized range test (HSD) was conducted to compare differences between treatments at $\alpha=0.05$ confidence level. Farm 1 and farm 2 were not grouped for statistical analysis due to dissimilar chemistry in manure at each farm. It was determined that there was no significant block effect on field emissions, therefore the emissions from the entire study for each treatment were determined by adding the emissions from the storage study to the average emissions of the two field plots for each respective treatment.

Emissions, manure characteristics, and soil characteristics were used in model selection to determine predictors of gaseous emissions. To determine correlation between gaseous emissions and manure and soil characteristics a Pearson Correlation Coefficient test of independence (Proc CORR) was ran in SAS. A multiple linear regression (Proc REG) using the stepwise selection function (Proc GLMSELECT) was calculated to predict gas emissions from CO_2 , CH_4 , N_2O , and NH_3 determined from manure and soil

characteristics. However only the NH_3 regression with parameters of EC, temperature, pH, and total N% of manure during storage is reported as it was the only gas for which a model was statistically significant.

3. Results and discussion

3.1. Manure characteristics

During storage, the TS content of the liquid and slurry manures remained relatively consistent while the TS content of the solid manures increased approximately 40% for both DS1 and S2 over the storage period due to moisture loss (Fig. B.1). The increased porosity and temperature of the solid manures likely caused them to dry at a much faster rate than the liquid and slurry manures. The VS from all manures remained relatively unchanged during the first 30 days except for DL1 and DS1 (Fig. B.1). After the first 30 days, VS content remained relatively constant for all manures. Total C and TKN showed very small differences between sampling dates and no discernible trend could be seen as the sampling and analytical variation may have caused values to increase then decrease (Fig. B.1). The raw slurry from farm 2, R2, had substantial crust formation within the barrel and maintained an approximately 75% crust cover (visual estimate) during storage due to the use of straw bedding. The raw slurry from farm 1, R1, displayed some crusting with crust coverage less than 25% of the surface area given that digested separated solids were used for bedding at this farm.

3.2. Ammonia

Digestion, D1, resulted in an 81% increase in cumulative NH_3 emissions compared to R1 over the entire study period (Fig. 1A) similar to previous studies (Koirala et al., 2013; Neerackal et al., 2015; Sun et al., 2014b). This increase in cumulative NH_3 emissions is expected due to the mineralization of organic N through the digestion process which increased $\text{NH}_4 + \text{NH}_3$ concentrations in manure from R1 to D1 by 22%. In the case of NH_3 , separation following digestion, DL1, was able to significantly reduce this impact by 28% as compared to D1, although overall emissions were still 32% greater than R1. Removal of TS through separation following digestion had a significant effect on reducing NH_3 emissions of DL1 from D1, similar to Neerackal et al. (2015), but the specific mechanism for reduction is not known as the $\text{NH}_3 + \text{NH}_4$ concentration did not decrease from D1 to DL1. Further, separation alone, L2+S2, did not significantly reduce NH_3 compared to R2. This is thought to be due to the presence of a crust on R2 which

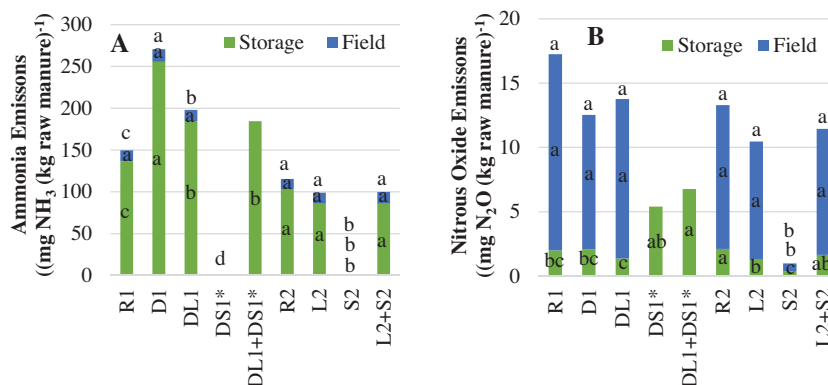


Fig. 1. Nitrogen emissions from liquid slurries and processed manures at both farms: (A) Ammonia (NH_3) and (B) Nitrous Oxide (N_2O). Treatments with similar letters (a, b, and c) at each farm did not show statistical significant difference at the $\alpha=0.05$ level, ANOVA was ran separately for each farm. *DS1 was removed for the field portion of the study, and was not applied to experimental plots.

served as a barrier to emissions (Aguerre et al., 2012). L2 did not have a crust form on the storage and had elevated NH_3 emissions. While digestion increased NH_3 emissions, it is important to note that there are many management practices, such as manure storage covers and using injection for land application, that can overcome this issues to reduce the overall impact.

Liquid and slurry manures resulted in significantly greater NH_3 emissions than separated solids during storage (Fig. 1A), suggesting mitigations strategies should be targeted at liquid and slurry manures. While some studies suggest this is the case (Dinuuccio et al., 2011, 2008) there are some that measured increased NH_3 emissions from manure solids (Amon et al., 2006). An increase in NH_3 emissions is likely when the method of solid manure storage increases aeration (Hansen et al., 2006). Amon et al. (2006) found that when separated solids are aerated NH_3 emissions will increase, up to 77% greater than anaerobically stacked manure solids.

Field application resulted in no treatment differences for NH_3 emissions, likely due to both the measurement system used and the manure incorporation method which has been shown to mitigate NH_3 emissions (Meisinger and Jokela, 2000; Powell et al., 2011). There is abundant literature on reductions of NH_3 when manure is rapidly incorporated (40–90%) (Dell et al., 2011; Hristov et al., 2011; Ndegwa et al., 2008; Powell et al., 2011; Webb et al., 2004; Wulf et al., 2002). However, while incorporation likely reduced the NH_3 concentrations of all treatments, the closed loop measurement system may have underestimated cumulative emissions. Miola et al. (2015) found that cumulative NH_3 emissions were underestimated by 23% when using static chamber 22 days after manure application. This difference was not statistically significant for 75% of the trials, and the difference decreased with the addition of a fan which was more similar to our closed loop system. In addition, Neerackal et al. (2015) determined that NH_3 emissions measured with a closed loop system (very similar to the design in this study) underestimated cumulative emissions compared to a laboratory dynamic system by 32–66%, but found the treatment differences remained consistent between the two measurement systems. While closed loop systems have been used extensively in literature, the results may underestimate NH_3 emissions overall, particularly when ammoniacal-N is low and the measurement period is short.

A multiple linear regression model was developed to predict NH_3 emissions from storage based on EC, manure temperature, pH, and total N. A significant regression was found ($F(4, 55) = 26.51$, $p < 0.0001$), with an R^2 of 0.659. Measured parameters predicted NH_3 emission $\text{ng (kg-manure s)}^{-1}$ according to Formula (1) where α = electric conductivity (us/cm), β = manure temperature ($^{\circ}\text{C}$), γ = pH, and δ = Total N (%).

$$y = 0.006 + 0.447\alpha + 3.49\beta + 23.5\gamma + 0.006\delta \quad (1)$$

Manure pH and temperature had significant positive regression weights indicating, as expected, that manure storages with higher pH and temperature resulted in higher emissions of NH_3 . Total N and EC reduced the error of the regression model, improving fit as indicated by the R^2 value, although their inclusion into the model was not statistically significant.

3.3. Nitrous oxide

Nitrous oxide emissions were greater for solid manures during storage compared to liquids and slurry manures, but the largest emissions of N_2O for all treatments were following land application of manure (Fig. 1B). N_2O from slurry and liquid storage is not expected to be a significant source of the total N_2O from manure systems as the anaerobic conditions prevent production, which is

supported by literature (Monteny et al., 2001; Sommer et al., 2000). The N_2O from digested separated solids was much higher than the separated solids without digestion, where DS1 had emissions of $5.4 \text{ mg N}_2\text{O/kg manure}$ and S2 has emissions of $0.4 \text{ mg N}_2\text{O/kg manure}$. Although both manures were similar in composition, including similar TKN concentrations of 1.35% and 1.24%, respectively, the mineralization during digestion resulted in an increase in $\text{NH}_4 + \text{NH}_3$ concentrations of 327 mg N/L for DS1 while S2 was much lower at 71 mg N/L . Higher concentrations of NH_4 have been linked to increased N_2O production (Sommer et al., 2000). While the increase in $\text{NH}_4 + \text{NH}_3$ through digestion likely contributed to the increase in N_2O , differences in animal diets and separator designs could also impact components contributing to N_2O emissions in the solid streams. While DL1 had a reduction in N_2O emissions as compared to R1, this mitigation was negated by DS1 as DL1 + DS1 significantly increased emissions from R1 by 240% in storage.

Separation has a 40% reduction in N_2O emissions from L2 as compared to R2 during storage, likely due to the crust formation in R2. Natural crust formation has been shown to enhance N_2O emissions (Aguerre et al., 2012) as it provides aerobic and anaerobic environments necessary for N_2O production (Sommer et al., 2000). The lack of a crust in the raw slurry at farm 1, R1, may also explain why there was no treatment difference in N_2O emissions following separation at farm 1. While separation can achieve a reduction in N_2O emissions from R2 to L2 during storage, the N_2O emission from S2 were much higher, resulting in a net increase from storage. While there was a 22% increase in the $\text{NH}_4 + \text{NH}_3$ concentration from R1 to D1, there was no corresponding increase in N_2O concentrations suggesting crust cover may be a more important factor for the production of N_2O emissions from manure storage. This theory is supported by those who suggest localized sites are critical for N_2O production (Rotz et al., 2012). Again, separation following digestion increased overall N_2O emissions from storage due to elevated N_2O emissions from the digested solids. However, in some cases solids are strictly land applied reducing the amount emitted from storage.

During the field portion of the study, the digested liquid manures, D1 and DL1, had N_2O emission reductions of 31% and 18% from R1, respectively (Fig. 1B). These reductions were not statistically different, which is explained by the relatively large standard deviation in emission of $4.3 \text{ mg N}_2\text{O kg raw manure}^{-1}$ of R1. During the first 80 days following application, with an exception of emissions on the first day and day 34, N_2O losses remained relatively constant. During this period soil $\text{NO}_2 + \text{NO}_3$ remained between 2 and 4 ppm and $\text{NH}_3 + \text{NH}_4$ decreased somewhat linearly from 6 to 8 ppm to around 2 ppm (Fig. 2). Soil moisture rose to ~50% on day 35 corresponding to a peak in N_2O emissions. An increase in soil moisture would have resulted in less oxygen which would have affected rates of denitrification (Bergstermann et al., 2011) thereby increasing N_2O emissions. The addition of urea 44 days after application resulted in an increase in soil $\text{NH}_3 + \text{NH}_4$ on day 77 (Fig. 2). The delay in release of $\text{NH}_3 + \text{NH}_4$ was most likely due to the use of the urease inhibitor. The increase in soil $\text{NH}_4 + \text{NH}_3$ on day 77 resulted in a peak in N_2O emissions on day 84. Soil temperature had no observed effect on N_2O emissions during this study (Fig. 3), similar to findings by Sommer et al. (2000).

The indirect formation of N_2O from NH_3 could increase GHG emissions from D1 by an additional $1.19 \text{ mg N}_2\text{O kg raw manure}^{-1}$ if the $0.01 \text{ kg N}_2\text{O-N kg NH}_3^{-1}$ IPCC factor for N_2O emissions from NH_3 is considered (Eggleston et al., 2006). This would increase the overall total GHG emission of D1 by 2% or from 7.43 to $7.55 \text{ g CO}_2\text{-eq kg raw manure}^{-1}$, which is still lower than the GHG emissions from R1 of $9.93 \text{ CO}_2\text{-eq kg raw manure}^{-1}$.

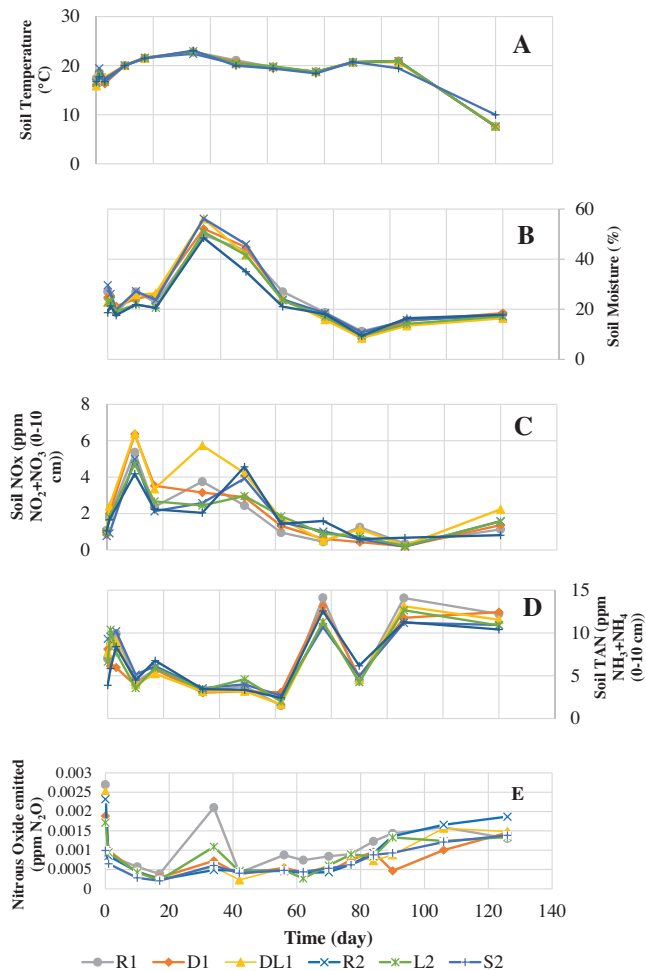


Fig. 2. N_2O emissions and soil characteristics over time (days) for each treatment over the field portion of the study: (A) Soil Temperature, (B) Soil moisture, (C) Soil $\text{NO}_2 + \text{NO}_3$ at the 0–10 cm depth, (D) Soil $\text{NH}_3 + \text{NH}_4$ at the 0–10 cm depth, and (E) N_2O emissions.

3.4. Methane

Methane emissions were greater during storage than land application for all treatments, as expected (Fig. 3A). AD and SLS both showed potential for mitigating CH_4 emissions during storage. The digested liquid manures, D1 and DL1, had a 25%

and 68% reduction in CH_4 emissions, respectively, during storage compared to R1, which can be explained by the significantly lower initial VS, NDF, TS, and C content (Table 1) than R1 (7% at $p < 0.05$ for D1 and 19% at $p < 0.001$ for DL1). Volatile solids and C are reduced during digestion as methanogens break down biomass to create CH_4 and CO_2 which is then captured and combusted. The separated solids from both farms, DS1 and S2, produced negligible amounts of CH_4 . Solid manure storage lacks the anaerobic conditions necessary for methanogenesis, as oxygen is allowed to penetrate due to its porosity, reducing the amount of CH_4 produced as compared to liquid or slurry manures. Additionally, easily degradable carbon for methanogenesis could remain in the liquid portion reducing the methane production potential of the separated solids.

Methane emissions were reduced during storage from D1 (25%), DL1+DS1 (68%), and L2+S2 (46%) than their respective raw slurries, R1 and R2, indicating that separation had a greater reduction in methane during storage than digestion. The reduction due to digestion is likely highly variable based on digester performance. The CH_4 emissions reductions during storage from DL1+DS1 were significantly less than D1 as stated above, indicating that separation further reduces CH_4 following digestion at a similar percentage to separation alone. Separated liquid manure from farm 2, L2, showed no significant difference when compared to R2 even though there was a very large change in CH_4 emissions due to a large standard deviation, $110 \text{ mg CH}_4 \text{ kg raw manure}^{-1}$. Emissions of CH_4 per gram of VS and CH_4 per gram of C were inconsistent among treatments, indicating that other physical and chemical differences, such as NDF, TS, environmental conditions, and crust coverage may have also played a role in CH_4 emissions.

3.5. Cumulative greenhouse gas emissions (nitrous oxide and methane)

All manure treatments released a majority of the total GHG emissions within the first 30 days of storage (Fig. 4). Emissions decreased over the next 49 days as temperatures in the barn dropped below 10°C . When the temperatures increased above 10°C around day 120 for the remainder of the study there was a corresponding increase in emissions. As expected, A Pearson Correlation Coefficient test of independence showed a strong interaction ($r = 0.684$, $p < 0.0001$) between GHG emissions and manure temperature. After land application of manure, cumulative GHG emissions for all treatments increased relatively linearly until

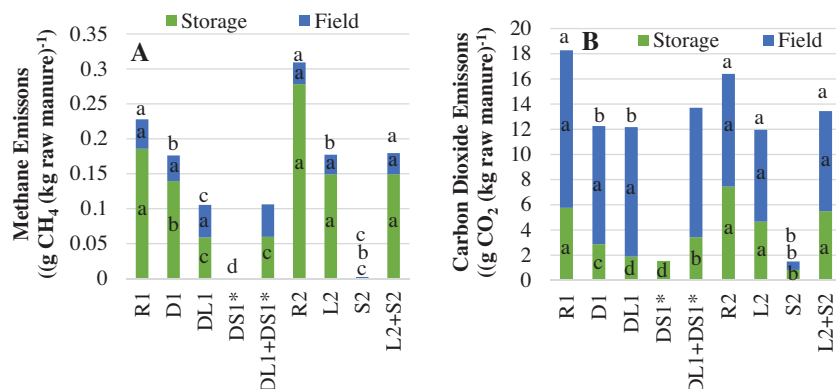


Fig. 3. Carbon emissions from liquid slurries and processed manures: (A) Methane (CH_4) and (B) Carbon dioxide (CO_2). Treatments with similar letters (a, b, and c) at each farm did not show statistical significant difference at the $\alpha = 0.05$ level, ANOVA was ran separately for each farm. *DS1 was removed for the field portion of the study, and was not applied to experimental plots.

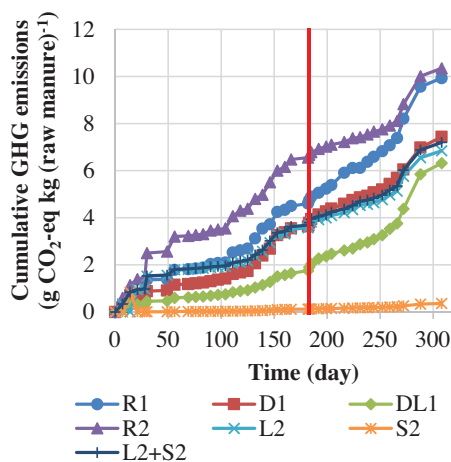


Fig. 4. Cumulative greenhouse gas emissions across storage and field stages of the study. Vertical red line indicates date manure was applied to the field separating the storage study from the field study. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the end of the study suggesting a consistent emission rate when manure is incorporated.

Digested manure, D1, had significantly less (25%) GHG emissions compared to R1 over the entire study period (storage and land application) (Fig. 5). Amon et al. (2006) also found a GHG emissions reduction from digestion following manure storage and application, the magnitude of the reduction was much greater at 59%. Though this previous study was conducted over a shorter time period with no replication, this highlights the range of variability in these experiments. One factor that may directly impact the emissions is the performance of the digester itself, where the level of degradation and carbon capture would greatly impact the downstream mitigation potential. The level of variability supports the need for greater mechanistic understanding to improve

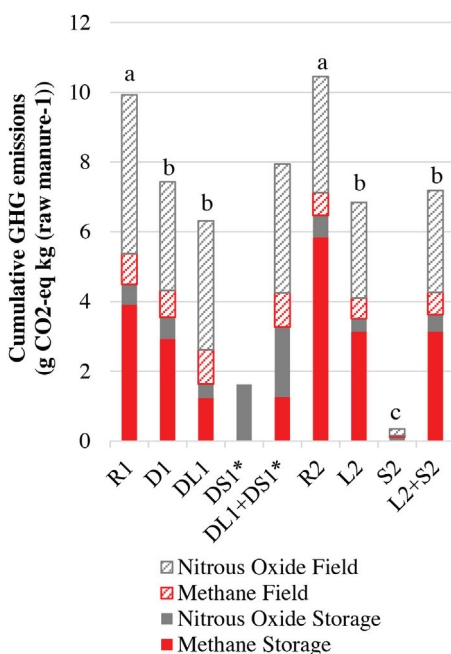


Fig. 5. Greenhouse gas emissions from raw slurries and processed manures proportioned by gas contributing and period of the study. Treatments with similar letters at each farm indicate no statistical difference at the $\alpha = 0.05$ level (ANOVA was ran separately for each farm). *DS1 was removed for the field portion of the study, and was not applied to experimental plots.

predictive models, while also the need to develop parameters to ensure digesters are reaching their potential to remove carbon.

With or without processing, the majority of the total GHG contributions from slurry and liquid storage were from CH₄ emissions and following land application were from N₂O (Fig. 5). When analyzing storage independently, D1 had a 21% reduction in total GHG emissions from R1 during the storage portion of the study. Separation did not further reduce cumulative GHG emissions from storage following digestion due to the increased emission of N₂O from the digested solids during storage. For separation alone, there was a significant reduction (44%) in the total GHG emissions over the entire study from R2 to L2+S2 because storage of the solids did not increase N₂O emissions enough to negate CH₄ mitigation. These results are similar to Amon et al. (2006) which measured a reduction of 37% and contrary to a previous laboratory study by Dinuccio et al. (2011) which concludes that separation of manure increased GHG emissions by 11% during storage and land application. The volatile solids were lower in the initial content of L2 when compared to R2, similar to Amon et al. (2006), resulting in a reduction in CH₄ emissions during storage as expected. However, Dinuccio et al. (2011) measured an increase in CH₄ emissions from separated liquids as compared to the raw slurry during storage even though the VS decreased in the separated liquid. Differences between the current study and Dinuccio et al. (2011) cannot be explained by the measured study parameters.

No GHG treatment differences existed after application of stored manure. After manure was incorporated, it appears that redox conditions were similar between treatments which resulted in similar emissions (Fig. 5). Overall, the methane emissions from storage were reduced by manure processing by 25%, 46%, and 68% for AD, SLS, and AD+SLS, respectively. However, these reductions from storage were somewhat negated when examining total GHG's to 44% and 27% for SLS and AD+SLS due to N₂O losses from solid storage. It is important to note that the reduction from AD in this study may have been low due to reduced performance in the digester, highlighting the need for proper design and operation to maximize C capture in the digester. In addition, managing solids is critical to reduce N₂O production in storage, where providing aeration can reduce N₂O losses.

3.6. Overall emissions and implications for future reductions

According to an inventory of U.S. GHG emissions and sinks in 2014 the dairy manure management emitted 35.5 MMT CO₂-eq of the 574.1 MMT CO₂-eq from agriculture (USEPA, 2016). Dairy manure management is defined by the USEPA as the treatment, storage, and transportation of livestock manure and estimates do not include CO₂. CH₄ accounted for 90% of the 35.5 MMT CO₂-eq from dairy manure management. Based on the results from this study, AD and immediate incorporation of manure following application results in a 25% reduction in CH₄. Therefore, if AD was incorporated at all dairies in the U.S., this would result in a reduction in ~7.2 MMT CO₂-eq. Incorporating AD and SLS further increased the reduction in CH₄ emissions to 40%. Extrapolating these results to all U.S. dairies increased the reduction to ~12.8 MMT CO₂-eq. While using large assumptions concerning manure, these estimates provide a basic understanding of the potential mitigation.

Ammonia loss during storage was the major contributor to losses of nitrogen (Table 3). Digestion increased the amount of ammonia lost in storage due to an increased concentration of ammoniacal nitrogen (Table 3). However, separation following digestion reduced nitrogen losses during storage and the first growing season following land application. Incorporation of SLS following digestion can reduce the ammonia losses in storage, but

the ammonia losses from storage of the digested and separated manure is still greater than the raw manure alone. In practice, it is likely that the solid manures will not be stored for as long as liquid manures, which may further mitigate this practice. However, other land application methods which do not immediately incorporate manure may further increase ammonia losses (Rotz et al., 2014a,b; Webb et al., 2010). Separation alone did show a trend in reduction but was not statistically significant in this study.

Emissions of NH_3 from dairy manure in the contiguous U.S. including emissions from housing, storage, and land application is estimated to be 370 Gg NH_3 per year from 2005 to 2008 (Paulot et al., 2014). Simulated NH_3 emissions from housing, storage, and field application are 18.2, 9.3, and 38.7 kg per cow from a free stall barn with slurry storage on representative dairy farm in Pennsylvania (Rotz et al., 2014a,b). If we assume that manure is immediately incorporated after broadcast 81% of the NH_3 is reduced (Rotz et al., 2014a,b). Given these results we can assume that 7.35 kg NH_3 per cow is lost during after application and housing accounts for 52% of emissions from the housing, storage, and land application of manure. In this study, AD resulted in an 81% increase in emissions of NH_3 meaning that if AD is implemented at all dairies in the U.S., this could result in an increase of 143 Gg NH_3 emissions per year. This estimate assumes that all dairies in the U.S. are free stall barns with manure storage with no cover and that manure applied is immediately incorporated. Given similar assumptions if AD and SLS is implemented at all dairies in the U.S. this would result in an increase of only 57 Gg NH_3 per year.

3.7. Carbon dioxide and carbon cycling

As expected, there are significant losses of carbon in the form of CO_2 during anaerobic storage of manure slurry and liquid. While CO_2 is a large source of GHG emissions from manure as found here and in many other studies (Dinuccio et al., 2011; Hao et al., 2004; Pattey et al., 2005), these emissions are considered to be recycled as part of the carbon cycle that takes places through photosynthesis during the production of crops that are fed to the cows. However, emissions of CO_2 are important as they for evaluation of the carbon cycling within the systems which is critical to mitigation and management strategies. Overall, the objective of manure processing is to reduce the carbon lost as CH_4 while that may increase the carbon lost as CO_2 .

Digestion significantly reduced not only the cumulative CH_4 emissions during storage, but also the cumulative CO_2 emissions

following digestion (Fig. 3B). However, C captured in the digester can be assumed to be released as CO_2 following combustion. Carbon dioxide emissions during storage for D1 and DL1 were 50% and 67% less than R1, respectively. Both D1 and DL1 had statistically lower initial total C than R1 due to losses during the digestion process with 30% and 48% less C content ($p < 0.1$ and $p < 0.01$, respectively). Emissions of CO_2 per gram of initial C from the entire study period were statistically similar between treatments, indicating that C content was the main driver of CO_2 emissions. DL1 + DS1 had a 19% increase in CO_2 emissions when compared to D1 during storage, which were mostly attributed to the solids portion. This solids fraction had a greater carbon content and the storage was likely more aerobic, both of which are drivers for C to be lost as CO_2 emissions as opposed to CH_4 for solid manure. Separation at farm 2 however reduced cumulative CO_2 emissions as L2 + S2 was 21% lower when compared to R2 during storage, but this reduction was not statistically significant as there was large standard deviation in R2. Although the CO_2 emissions from the solid fraction during storage are less than the CO_2 emissions from the separated liquid fraction at both farms, the solids are the main driver for the net change in CO_2 during storage. The majority of carbon was lost during the storage of manure and was emitted as CO_2 (Table 2).

Manure processing using AD or SLS was able to reduce the carbon lost during manure storage and after one growing season following field application. Digested manure had a reduced amount of initial C (due to the captured C during the digestion process) and had significantly less C loss from storage and application (44%) than their respective raw manures (Table 2). However, it is important to consider the amount of carbon lost during anaerobic digestion to determine its effect on C. The separated liquids DL1, and L2 also had significantly less C loss (58%, and 43%, respectively) than their respective raw manures over the entire study span. The combined C emissions from the L2 and S2 was less than R2 from the entire study span, indicating that separation was effective in reducing carbon losses from storage and land application, although this was not statically significant. Manure processing of AD and SLS was able to reduce the total C lost through the system for the time period of the study. The ratio of C lost as CH_4 and CO_2 remained consistent, meaning that reductions of CH_4 did not result in short increases in CO_2 . This suggests that these manure processing systems avoid short term losses of C, which will likely be lost as biotic CO_2 emissions from the soil over a much longer period of time (Table 2).

Table 2

Carbon balance for all treatments during the study. Farm 1 raw manure (R1), farm 1 digested manure (D1), farm 1 digested separated liquid (DL1), farm 1 digested separated solids (DS1), farm 2 manure (R2), farm 2 separated liquid (L2); farm 2 separated solids (S2).

	R1	D1	DL1	DS1	R2	L2	S2
Initial C (mg (kg raw slurry) ⁻¹)	22,833	16,300	11,400	232,533	14,833	12,200	177,200
C Lost Storage (mg (kg raw slurry) ⁻¹)	1973	1016	644	491	2577	1595	264
C Lost Field (mg (kg raw slurry) ⁻¹)	430	326	362	NA	308	253	23
Total C Lost (mg (kg raw slurry) ⁻¹)	2402	1343	1006	NA	2830	1617	264
C Emitted (%)	10.5	8.2	8.8	NA	19.1	13.3	0.1
Total CO_2 (mg (kg raw slurry) ⁻¹)	7013	3804	2913	NA	8339	5389	896
Total C lost as CO_2 (%)	93	90	93	NA	92	93	99
Total CH_4 (mg (kg raw slurry) ⁻¹)	228	176	105	NA	309	177	2
Total C lost as CH_4 (%)	7	10	8	NA	8	7	1

Table 3
Nitrogen balance for all treatments during the study. Farm 1 raw manure (R1), farm 1 digested manure (D1), farm 1 digested separated liquid (DL1), farm 1 digested separated solids (DS1), farm 2 manure (R2), farm 2 separated liquid (L2); farm 2 separated solids (S2).

	R1	D1	DL1	DS1	R2	L2	S2
Initial N (mg (kg raw slurry) ⁻¹)	2205	2337	2369	13,417	1838	1842	12,500
N Lost Storage (mg (kg raw slurry) ⁻¹)	113	211	152	2	86	71	0
N Lost Field (mg (kg raw slurry) ⁻¹)	16	16	15	NA	13	14	1
Total N Lost (mg (kg raw slurry) ⁻¹)	129	227	167	NA	100	72	1
N Emitted%	5.8	9.7	7.1	NA	5.4	3.9	0.01
Total NH ₃ Lost (mg (kg raw slurry) ⁻¹)	150	271	198	NA	116	99	1
Total N ₂ O Lost (mg (kg raw slurry) ⁻¹)	17	13	14	NA	13	10	1

4. Conclusions

AD significantly reduces emissions of CH₄ from storage (25%) resulting in an overall reduction of GHG emissions. SLS reduced CH₄ emissions from storage by 46% alone and by an additional 43% following digestion (total CH₄ reduction in storage of 68% for AD + SLS). This indicates that SLS has a greater mitigation potential for methane in storage than AD, but this likely varies highly depending upon the digester performance. However, combining AD and SLS does not further reduce total GHG emissions from storage than AD alone as anaerobically stacking digested solids increased emissions of N₂O negating abatement of total GHG. AD could also significantly increase NH₃ emissions from manure storages if manure covers are not implemented, although combining AD and SLS could reduce the amount of NH₃ lost following digestion.

Acknowledgements

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The authors would like to acknowledge Kris Niemann, Jeff Wilkins, Ali Pelletier, and Claire Campbell for their help with data collection during the study.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.agee.2017.02.007>.

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Exhibit 2



San Joaquin Valley

AIR POLLUTION CONTROL DISTRICT



DEC 17 2010

Jim Rexroad
Avenal Power Center LLC
500 Dallas Street, Level 31
Houston, TX 77002

Re: Notice of Final Determination of Compliance (FDOC)
Project Number: C-1100751 – Avenal Power Center LLC (08-AFC-01)

Dear Mr. Rexroad:

Enclosed is the District's final determination of compliance (FDOC) for the installation of a nominal 600 MW combined cycle power plant, located at NE¼ Section 19, T21S, R18E – Mount Diablo Base Meridian on Assessor's Parcel Number 36-170-035 in Avenal, CA.

Notice of the District's preliminary decision was published on July 27, 2010. All comments received following the District's preliminary decision on this project were considered. A summary of the comments received and the District responses to those comments can be found in Attachments J, K, L, and M of the enclosed FDOC package.

The changes made to the PDOC were in direct response to comments received from the oversight agencies and other interested parties. It is District practice to require an additional 30-day comment period for a project if changes received during the initial 30-day comment period result in a significant emissions increase that affects or modifies the original basis for approval. The changes made were minor and did not increase permitted emission levels or trigger additional public notification requirements. Therefore, publication of the PDOC for an additional 30-day comment period is not required.

Also enclosed is an invoice for the engineering evaluation fees pursuant to District Rule 3010. Please remit the amount owed, along with a copy of the attached invoice, within 60 days.

Sayed Sadredin
Executive Director/Air Pollution Control Officer

Northern Region
4800 Enterprise Way
Modesto, CA 95356-8718
Tel: (209) 557-6400 FAX: (209) 557-6475

Central Region (Main Office)
1990 E. Gettysburg Avenue
Fresno, CA 93726-0244
Tel: (559) 230-6000 FAX: (559) 230-6061
www.valleyair.org

Southern Region
34946 Flyover Court
Bakersfield, CA 93308-9725
Tel: 661-392-5500 FAX: 661-392-5585
www.healthyairliving.com

Mr. Jim Rexroad
Page 2

Thank you for your cooperation in this matter. If you have any questions, please contact Mr. Jim Swaney of the Permit Services Division at (559) 230-5900.

Sincerely,

A handwritten signature in dark ink, appearing to read "D. Warner", with a long horizontal flourish extending to the right.

David Warner
Director of Permit Services

DW:df

Enclosures

cc: Gary Rubenstein, Sierra Research



San Joaquin Valley

AIR POLLUTION CONTROL DISTRICT



DEC 17 2010

Mike Tollstrup, Chief
Project Assessment Branch
Stationary Source Division
California Air Resources Board
PO Box 2815
Sacramento, CA 95812-2815

Re: Notice of Final Determination of Compliance (FDOC)
Project Number: C-1100751 – Avenal Power Center LLC (08-AFC-01)

Dear Mr. Tollstrup:

Enclosed is the District's Final Determination of Compliance (FDOC) for the installation of a nominal 600 MW combined cycle power plant, located at NE¼ Section 19, T21S, R18E – Mount Diablo Base Meridian on Assessor's Parcel Number 36-170-035 in Avenal, CA.

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Thank you for your cooperation in this matter. If you have any questions, please contact Mr. Jim Swaney of the Permit Services Division at (559) 230-5900.

Sincerely,

David Warner
Director of Permit Services

DW:df

Enclosures

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San Joaquin Valley

AIR POLLUTION CONTROL DISTRICT



DEC 17 2010

Gerardo C. Rios (AIR 3)
Chief, Permits Office
Air Division
U.S. E.P.A. - Region IX
75 Hawthorne Street
San Francisco, CA 94105

Re: Notice of Final Determination of Compliance (FDOC)
Project Number: C-1100751 – Avenal Power Center LLC (08-AFC-01)

Dear Mr. Rios:

Enclosed is the District's Final Determination of Compliance (FDOC) for the installation of a nominal 600 MW combined cycle power plant, located at NE¼ Section 19, T21S, R18E – Mount Diablo Base Meridian on Assessor's Parcel Number 36-170-035 in Avenal, CA.

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The changes made to the Preliminary Determination of Compliance (PDOC) were in direct response to comments received from the oversight agencies and other interested parties. It is District practice to require an additional 30-day comment period for a project if changes received during the initial 30-day comment period result in a significant emissions increase that affects or modifies the original basis for approval. The changes made were minor and did not increase permitted emission levels or trigger additional public notification requirements. Therefore, publication of the PDOC for an additional 30-day comment period is not required.

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Sincerely,

David Warner
Director of Permit Services

DW:df

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San Joaquin Valley

AIR POLLUTION CONTROL DISTRICT

DEC 17 2010

Joseph Douglas
Project Manager
California Energy Commission
1516 Ninth Street
Sacramento, CA 95814



HEALTHY AIR LIVING™

Re: Notice of Final Determination of Compliance (FDOC)
Project Number: C-1100751 – Avenal Power Center LLC (08-AFC-01)

Dear Mr. Douglas:

Enclosed is the District's Final Determination of Compliance (FDOC) for the installation of a nominal 600 MW combined cycle power plant, located at NE¼ Section 19, T21S, R18E – Mount Diablo Base Meridian on Assessor's Parcel Number 36-170-035 in Avenal, CA.

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Sincerely,

David Warner
Director of Permit Services

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Fresno Bee

NOTICE OF FINAL DETERMINATION OF COMPLIANCE

NOTICE IS HEREBY GIVEN that the San Joaquin Valley Unified Air Pollution Control District has issued a Final Determination of Compliance (FDOC) to Avenal Power Center LLC for the installation of a nominal 600 MW combined cycle power plant, located at NE¼ Section 19, T21S, R18E – Mount Diablo Base Meridian on Assessor's Parcel Number 36-170-035 in Avenal, CA.

All comments received following the District's preliminary decision on this project were considered. Changes were made to the DOC in direct response to comments received from the oversight agencies and other interested parties. The changes made were minor and did not increase permitted emission levels or trigger additional public notification requirements.

The application review for project C-1100751 is available for public inspection at http://www.valleyair.org/notices/public_notices_idx.htm and the **SAN JOAQUIN VALLEY UNIFIED AIR POLLUTION CONTROL DISTRICT, 1990 EAST GETTYSBURG AVENUE, FRESNO, CA 93726.**

FINAL DETERMINATION OF COMPLIANCE EVALUATION

Avenal Power Center Project California Energy Commission Application for Certification Docket #: 08-AFC-01

Facility Name: Avenal Power Center, LLC
Mailing Address: 500 Dallas Street, Level 31
Houston, TX 77002

Contact Name: Jim Rexroad
Telephone: (713) 275-6147
Fax: (713) 275-6115
Cell: (832) 748-1060
E-Mail: jim.Rexroad@macquarie.com

Alternate Contact: Eric Walther
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Alternate Contact: Tracey Gilliland
Telephone: (713) 275-6148
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Engineer: Derek Fukuda, Air Quality Engineer
Lead Engineer: Joven Refuerzo, Supervising Air Quality Engineer

Project #: C-1100751
Application #'s: C-3953-10-1, C-3953-11-1, C-3953-12-1, C-3953-13-1, and
C-3953-14-1
Submitted: March 3, 2010

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I. PROPOSAL:

Avenal Power Center, LLC is seeking approval from the San Joaquin Valley Air Pollution Control District (the "District") for the installation of a "merchant" electrical power generation facility (Avenal Energy Project). The Avenal Energy Project will be a combined-cycle power generation facility consisting of two natural gas-fired combustion turbine generators (CTGs) each with a heat recovery steam generator (HRSG) and a 564 MMBtu/hr duct burner. Also proposed are a 300 MW steam turbine, a 37.4 MMBtu/hr auxiliary boiler, a 288 hp diesel-fired emergency IC engine powering a water pump, a 860 hp natural gas-fired emergency IC engine powering a 550 kW generator and associated facilities. The plant will have a nominal rating of 600 MW.

While Avenal Power Center, LLC has already received a Determination of Compliance for the above described facility, they are now proposing to limit the annual facility wide NO_x emissions from 288,618 lb/year to 198,840 lb/year, and the annual facility wide CO emissions from 1,205,418 lb/year to 197,928 lb/year. The effect of these limits will be two-fold: one, should the facility operate to its full permitted extent, it will have the lowest annual average permitted emissions of NO_x (0.045 lb-NO_x/MWh) and CO (0.044 lb-CO/MWh) of any natural gas fired power plant known to the District; and two, the facility will be limited to less than the 100 tons/year major source thresholds of the federal prevention of significant deterioration program.

The Avenal Energy Project is subject to approval by the California Energy Commission (CEC). Pursuant to SJVAPCD Rule 2201, Section 5.8, the Determination of Compliance (DOC) review is functionally equivalent to an Authority to Construct (ATC) review. The Determination of Compliance (DOC) will be issued and submitted to the CEC contingent upon SJVAPCD approval of the project.

The California Energy Commission (CEC) is the lead agency for this project for the requirements of the California Environmental Quality Act (CEQA).

The facility submitted an application to revise their existing DOC issued under Project C-1080386. This revision consists of limiting the annual facility wide NO_x emissions to 198,840 lb/year, and the annual facility wide CO emissions to 197,928 lb/year. The equipment the DOC was issued for in project C-1080386 has not been implemented. All units in this project will be treated as new emissions units.

II. APPLICABLE RULES:

Rule 1080	Stack Monitoring (12/17/92)
Rule 1081	Source Sampling (12/16/93)
Rule 1100	Equipment Breakdown (12/17/92)
Rule 2010	Permits Required (12/17/92)
Rule 2201	New and Modified Stationary Source Review Rule (9/21/06)
Rule 2520	Federally Mandated Operating Permits (6/21/01)
Rule 2540	Acid Rain Program (11/13/97)

- Rule 2550** Federally Mandated Preconstruction Review for Major Sources of Air Toxics (6/18/98)
- Rule 4001** New Source Performance Standards (4/14/99)
Subpart Dc - Standards of Performance for Small Industrial-Commercial-Institutional Steam Generating Units
Subpart GG - Standards of Performance for Stationary Gas Turbines
Subpart IIII – Standards of Performance for Stationary Compression Ignition Internal Combustion Engines
Subpart JJJJ -Standards of Performance for Stationary Spark Ignition Internal Combustion Engines
Subpart KKKK – Standards of Performance for Stationary Combustion Turbines
- Rule 4002** National Emissions Standards for Hazardous Air Pollutants (5/20/2004)
Subpart ZZZZ - National Emission Standard for Hazardous Air Pollutants for Stationary Reciprocating Internal Combustion Engines
- Rule 4101** Visible Emissions (2/17/05)
- Rule 4102** Nuisance (12/17/92)
- Rule 4201** Particulate Matter Concentration (12/17/92)
- Rule 4202** Particulate Matter Emission Rate (12/17/92)
- Rule 4301** Fuel Burning Equipment (12/17/92)
- Rule 4305** Boilers, Steam Generators and Process Heaters – Phase 2 (8/21/03)
- Rule 4306** Boilers, Steam Generators and Process Heaters – Phase 3 (10/16/08)
- Rule 4351** Boilers, Steam Generators and Process Heaters – Phase 1 (8/21/03)
- Rule 4701** Stationary Internal Combustion Engines – Phase 1 (8/21/03)
- Rule 4702** Stationary Internal Combustion Engines – Phase 2 (1/18/07)
- Rule 4703** Stationary Gas Turbines (9/20/07)
- Rule 4801** Sulfur Compounds (12/17/92)
- Rule 8011** General Requirements (8/19/04)
- Rule 8021** Construction, Demolition, Excavation, Extraction and Other Earthmoving Activities (8/19/04)
- Rule 8031** Bulk Materials (8/19/04)
- Rule 8041** Carryout and Trackout (8/19/04)
- Rule 8051** Open Areas (8/19/04)
- Rule 8061** Paved and Unpaved Roads (8/19/04)
- Rule 8071** Unpaved Vehicle/Equipment Traffic Areas (9/16/04)
- Rule 8081** Agricultural Sources (9/16/04)

California Environmental Quality Act (CEQA)

California Code of Regulations (CCR), Section 2423 (Exhaust Emission Standards and Test Procedures, Off-Road Compression-Ignition Engines and Equipment)

California Health & Safety Code (CH&S), Sections 2423 (Exhaust Emission Standards and Test Procedures, Off-Road Compression-Ignition Engines and Equipment) 41700 (Health Risk Analysis), 42301.6 (School Notice), 44300 (Air Toxic “Hot Spots”), and 93115 (Airborne Toxic Control Measure (ATCM) for Stationary Compression-Ignition (CI) Engines)

III. PROJECT LOCATION:

The proposed equipment will be located within NE¼ Section 19, Township 21 South, Range 18 East – Mount Diablo Base Meridian on Assessor's Parcel Number 36-170-035 (See Attachment B). The closest population center is the residential district of Avenal approximately 6 miles to the southwest. The City of Huron is located approximately 8 miles to the north, and the City of Coalinga is located approximately 16 miles to the west.

The site is located northeast of the city of Avenal, in Kings County. The proposed location is not within 1,000' of a K-12 school.

IV. PROCESS DESCRIPTION:

Combined-Cycle Combustion Turbine Generators

Each natural gas-fired General Electric Frame 7 Model PG7241FA combined-cycle combustion turbine generator (CTG) will be equipped with Dry Low NO_x combustors, a selective catalytic reduction (SCR) system with ammonia injection, an oxidation catalyst, a duct burner, and a heat recovery steam generator (HRSG). Each CTG will drive an electrical generator to produce approximately 180 MW of electricity. The plant will be a "combined-cycle plant," since the gas turbine and a steam turbine both turn electrical generators and produce power.

Each CTG will turn an electrical generator, but will also produce power by directing exhaust heat through its HRSG, which supplies steam to the steam turbine nominally rated at 300 MW, which turns another electrical generator.

Since two HRSGs will feed a single steam turbine generator, this design is referred to as a "two-on-one" configuration.

The CTGs will utilize Dry Low NO_x (DLN) combustors, SCR with ammonia injection, and an oxidation catalyst to achieve the following emission rates:

NO_x: 2.0 ppmvd @ 15% O₂
VOC: 2.0 ppmvd @ 15% O₂
CO: 2.0 ppmvd @ 15% O₂
SO_x: 0.00282 lb/MMBtu (Hourly and Daily Limits; based on 1.0 gr S/100 dscf)
0.001 lb/MMBtu (Annual average; based on 0.36 gr S/100 dscf)
PM₁₀: 0.0048 lb/MMBtu (without duct burner firing)
0.0050 lb/MMBtu (with duct burner firing)

Continuous emissions monitoring systems (CEMs) will sample, analyze, and record NO_x, CO, and O₂ concentrations in the exhaust gas for each CTG.

Heat Recovery Steam Generators (HRSGs)

The HRSGs provide for the transfer of heat from the CTG exhaust gases to condensate and feedwater to produce steam. Each HRSG will be approximately 90 feet high and will have an exhaust stack approximately 145 feet tall by 19 feet in diameter. The size and shape of the

Post-project Stationary Source Potential to Emit [SSPE2] (lb/year)							
Permit Unit	NO _x *	CO **	VOC	PM ₁₀	SO _x	NH ₃	PM _{2.5} ***
C-3953-10-1	198,840	197,928	34,489	80,656	16,694	219,972	80,656
C-3953-11-1			34,489	80,656	16,694	219,972	80,656
C-3953-12-1			201	233	132	0	233
C-3953-13-1			12	2	0	0	2
C-3953-14-1			31	3	1	0	3
Post-project SSPE (SSPE2)	198,840	197,928	69,222	161,550	33,521	439,944	161,550

* The facility has proposed to limit the NO_x emission from this facility to 198,840 lb/year.

** The facility has proposed to limit the CO emission from this facility to 197,928 lb/year.

*** All PM₁₀ emissions are PM_{2.5}.

5. Major Source Determination

Pursuant to Section 3.24 of District Rule 2201, a major source is a stationary source with post-project emissions or a Post-project Stationary Source Potential to Emit (SSPE2), equal to or exceeding one or more of the following threshold values.

Major Source Determination						
	NO _x (lb/year)	CO (lb/year)	VOC (lb/year)	PM ₁₀ (lb/year)	SO _x (lb/year)	PM _{2.5} (lb/year)
Post-project SSPE (SSPE2)	198,840	197,928	69,222	161,550	33,521	161,550
Major Source Threshold	50,000	200,000	50,000	140,000	140,000	200,000
Major Source?	Yes	No	Yes	Yes	No	No

6. Annual Baseline Emissions (BE)

Per District Rule 2201, Section 3.7, the baseline emissions, for a given pollutant, shall be equal to the pre-project potential to emit for:

- Any emission unit located at a non-major source,
- Any highly utilized emission unit, located at a major source,
- Any fully-offset emission unit, located at a major source, or
- Any clean emission unit located at a major source

otherwise,

BE = Historic Actual Emissions (HAE), calculated pursuant to Section 3.22 of District Rule 2201

As shown above, this facility will be a major source for NO_x, VOC, and PM₁₀ emissions after this project. However, since the units in this project are all new emissions units, there are no historical actual emissions or pre-project potential to emit. Therefore, the baseline NO_x, CO, VOC, PM₁₀ and SO_x emissions will be set equal to the following:

BE = 0 lb/year

7. Major Modification

Major Modification is defined in 40 CFR Part 51.165 as *"any physical change in or change in the method of operation of a major stationary source that would result in a significant net emissions increase of any pollutant subject to regulation under the Act."*

Since this is a new facility, this project cannot be considered a Major Modification.

8. Federal Major Modification

As shown above, this project does not constitute a Major Modification. Therefore, in accordance with District Rule 2201, Section 3.17, this project does not constitute a Federal Major Modification and no further discussion is required.

VIII. COMPLIANCE:

Rule 1080 Stack Monitoring

This Rule grants the APCO the authority to request the installation and use of continuous emissions monitors (CEMs), and specifies performance standards for the equipment and administrative requirements for recordkeeping, reporting, and notification.

i. C-3953-10-1 and C-3953-11-1 (Turbines)

The two CTGs will be equipped with operational CEMs for NO_x, CO, and O₂. Provisions included in the operating permit are consistent with the requirements of this Rule. Compliance with the requirements of this Rule is anticipated.

iii. C-3953-13-1 (Diesel IC engine powering fire water pump)

BACT has been satisfied by the following:

NO_x: Certified NO_x emissions of 6.9 g/hp · hr or less

VOC: No VOC control. Any add on VOC control device would void the Underwriters Laboratory (UL) certification.

iv. C-3953-14-1 (Natural gas IC engine powering electrical generator)

BACT has been satisfied by the following:

NO_x: = or < 1.0 g/bhp-hr (lean burn natural gas fired engine, or equal)

VOC: 90% control efficiency (oxidation catalyst, or equal)

Therefore, the following condition will be listed on the DOC to ensure compliance:

- {3492} This IC engine shall be equipped with a three-way catalyst. [District Rule 2201]

C. Offsets:

1. Offset Applicability:

Pursuant to Section 4.5.3, offset requirements shall be triggered on a pollutant by pollutant basis and shall be required if the Post-project Stationary Source Potential to Emit (SSPE2) equals to or exceeds emissions of 20,000 lbs/year for NO_x and VOC, 200,000 lbs/year for CO, 54,750 lbs/year for SO_x and 29,200 lbs/year for PM₁₀. As seen in the table below, the facility's SSPE2 is greater than the offset thresholds for NO_x, CO, VOC, PM₁₀, and SO_x emissions. Therefore, offset calculations are necessary.

Offset Determination					
	NO _x (lb/year)	CO (lb/year)	VOC (lb/year)	PM ₁₀ (lb/year)	SO _x (lb/year)
Post-project SSPE (SSPE2)	198,840	197,928	69,222	161,550	33,521
Offset Threshold	20,000	200,000	20,000	29,200	54,750
Offsets Required?	Yes	No	Yes	Yes	No

Exhibit 3

	NOx	SOx	PM10	CO	VOC	PM2.5	MW/hour	% of Avenal Electricity
One Digester (lbs/year)	9,166	2,268	3,970	101,636	6,370	3970	1.059	
One Digester (tons/year)	4.58	1.13	1.99	50.82	3.19	1.99		
25 Digesters (lbs/year)	229,150	56,700	99,250	2,540,900	159,250	99,250	26.475	4.41%
25 Digesters (tons/year)	114.58	28.35	49.63	1,270.45	79.63	49.63		
Avenal (lbs/year)	198,840	33,521	161,550	197,928	69,222	161550	600	
Avenal (tons/year)	99.42	16.76	80.78	98.96	34.61	80.775		
Pollution Difference Digesters vs. Avenal (tons/year)	15.16	11.59	-31.15	1,171.49	45.01	-31.15		

Source: Avenal Power Center Authority to Construct Permit No. December 17, 2010, Post-Project Stationary Source Potential to Emit (SSPE2) at 27.

Source: Lakeview Dairy Biogas digester Authority to Construct Permit March 22, 2016, Post-Project Stationary Source Potential to Emit (SSPE2) at 14, 20